APPENDIX K
GREENHOUSE GAS ESTIMATE ANALYSIS

Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). There are also several gases that do not have a direct radiative forcing effect but that do influence the formation and destruction of ozone, which has a radiation absorbing effect. Three of the direct greenhouse gases are formed by the combustion of fossil fuels; CO_2, CH_4, and N_2O. The indirect gases include the NO_x, CO, and non-methane volatile organic compounds (NMVOC) all of which are emitted from the combustion of fossil fuels.

The IPCC has published three volumes of guidelines for international use in determining greenhouse inventories.1 One of these volumes is the *Reference Manual,* which contains calculation methodologies that are arranged in tiers of increasing complexity. The Tier 1 methods provide simple calculations based on the quantities of fuel consumed and average emission factors. Tier 2 and 3 methods use detailed fuel and technology information for estimating emissions from stationary and mobile sources. Tier 1 methodology was used to determine the emissions presented here.

The primary greenhouse gas emission from the energy sector is CO_2. Most carbon contained in fossil fuels is emitted as CO_2 during the fuel combustion process. The remainder is emitted as CO, CH_4, or non-methane volatile organic compounds, all of which oxidize to CO_2 in the atmosphere within a time range of a few days to nearly 11 years. The Tier 1 method accounts for all of the carbon from these emissions in the total for CO_2. Unoxidized carbon in the form of unburned or partly oxidized soot or ash is not included in the gas emissions.

The Tier 1 method estimates carbon emissions from the amount of fuel burned and the carbon content of the fuel. The project-specific fuel usage and fuel characteristics were used to determine the CO_2 emissions. The IPCC estimates that less than 1 percent of the carbon is unoxidized during the combustion of natural gas; a value of 0.5 percent is recommended.2 Emissions of CO_2 were determined using the equations and the values and sources shown:3

$$CO_2\ Emissions =$$
$$\left[Fuel\ Consumed \times Fuel\ Carbon\ Content - Carbon\ Stored\ in\ \mathrm{Pr}oducts\right] \times Fraction\ Oxidized$$

Where:

Fuel consumed per CGT = 81,510 lb/hr [per Black and Veatch (B&V)]
Fuel consumed per Duct Burner (DB) = 26,272 lb/hr (per B&V)
Total Fuel consumed = [(81, 510+26,272)]*2 = 215,564 lb/hr
Fuel Carbon Content = 68.78 weight percent (per B&V)
Ambient Temperature = -20^{o}F
Capacity Factor = 1 (100% Load)
Operating Schedule = (366 days/yr)*(24 hrs/day) = 8,784/yr

$$CO_2\ Emissions =$$

$$\left[1{,}215{,}564\ \frac{lb}{hr} \times 0.6878 - 0\right] \times 0.995 \times 0.9072\ \frac{metric\ tons}{2000\ lb} \times 8{,}784\ \frac{hr}{yr} \times \frac{44\ lb\ CO_2}{12\ lb\ C}$$

$$CO_2\ Emissions = 2{,}155{,}253\ \frac{metric\ tons\ CO_2}{yr}$$

and where:

$$Energy\ Input\ (Heat\ Input) = [3{,}106.8 + 1{,}018.8] \times 10^6\ \frac{Btu}{hr}\ (per\ B\ \&\ V)$$

$$Net\ Energy\ Rate\ (Net\ Heat\ Rate) = 6{,}895\ \frac{Btu}{KWh}\ (LHV)\ (per\ B\ \&\ V)$$

$$CO_2\ Emissions =$$

$$2{,}155{,}253 \times 10^3\ \frac{Kg}{yr} \times \frac{yr}{8{,}784\ hr} \times \frac{6{,}895\ Btu}{KWh} \times \frac{hr}{4{,}125.6 \times 10^6\ Btu} \times \frac{10^3\ KWh}{MWh}$$

$$CO_2\ Emissions = 410.1\ \frac{Kg\ CO_2}{MWh}$$

Methane emissions result from the incomplete combustion of natural gas and are minor. An uncontrolled emission factor of 1 kilogram (kg) per Tera (10^{12}) Joule (TJ) of fuel consumed was developed by the IPCC based on several studies published between 1990 and 1995.[4] Emissions of CH_4 were determined using the following equation and source-specific fuel consumption rates:

$$CH_4\ Emissions = EF_{natural\ gas} \times Energy\ Input$$

Where:

$$EF_{natural\ gas} = 1\ \frac{Kg\ \ CH_4}{TJ}\ (per\ IPCC)$$

$$Energy\ Input\ (Heat\ Input) = [3{,}106.8 + 1{,}018.8] \times 10^6\ \frac{Btu}{hr}\ (per\ B\ \&\ V)$$

$$Energy\ Input =$$

$$[3{,}106.8 + 1{,}018.8] \times 10^6\ \frac{Btu}{hr}\ \times 1055 \times 10^{-12}\ \frac{TJ}{Btu} \times 8{,}784\ \frac{hr}{yr} = 38{,}733\ \frac{TJ}{yr}$$

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4 J T Houghton op.cit., § 1.4.2.1, Table 1-7.

$$CH_4\ Emissions = 1\,\frac{Kg}{TJ} \times 38{,}733\,\frac{TJ}{yr} \times \frac{1\,metric\ ton}{10^3\ Kg} = 38.73\,\frac{metric\ tons\ CH_4}{yr}$$

and where:

$$Net\ Energy\ Rate\ (Net\ Heat\ Rate) = 6{,}895\,\frac{Btu}{KWh}\,(LHV)\,(per\ B\,\&\,V)$$

$$CH_4\ Emissions = 1\,\frac{Kg}{TJ} \times \frac{10^{-12}\,TJ}{1{,}055\ Btu} \times 6{,}895\,\frac{Btu}{KWh} \times \frac{10^3\ KWh}{MWh} = 6.53 \times 10^{-9}\,\frac{Kg\ \ CH_4}{MWh}$$

Nitrous oxide is produced directly from the combustion of fossil fuels. It has been determined that combustion temperatures below 800 K or over 1200 K produce negligible amounts of N_2O. A default uncontrolled emission factor of 0.1 kg/TJ of fuel consumed was developed by the IPCC based on several studies published between 1990 and 1994.[5] Emissions of N_2O were determined using the following equation and source-specific fuel consumption rates:

$$N_2O\ Emissions = EF_{natural\ gas} \times Energy\ Input$$

Where:

$$EF_{natural\ gas} = 0.1\,\frac{Kg\ \ N_2O}{TJ}\,(per\ IPCC)$$

$$Energy\ Input\ (Heat\ Input) = [3{,}106.8 + 1{,}018.8] \times 10^6\,\frac{Btu}{hr}\,(per\ B\,\&\,V)$$

$$N_2O\ Emissions = 0.1\,\frac{Kg}{TJ} \times 38{,}733\,\frac{TJ}{yr} \times \frac{1\,metric\ ton}{10^3\ Kg} = 3.87\,\frac{metric\ tons\ N_2O}{yr}$$

and where:

$$Net\ Energy\ Rate\ (Net\ Heat\ Rate) = 6{,}895\,\frac{Btu}{KWh}\,(LHV)\,(per\ B\,\&\,V)$$

$$N_2O\ Emissions =$$

$$0.1\,\frac{Kg}{TJ} \times \frac{10^{-12}\,TJ}{1{,}055\ Btu} \times 6{,}895\,\frac{Btu}{KWh} \times \frac{10^3\ KWh}{MWh} = 0.653 \times 10^{-9}\,\frac{Kg\ \ N_2O}{MWh}$$

The emissions of the indirect greenhouse gases shown in the Table K-1 have been determined by using source-specific emission rates and the following equation:

$$Emissions = Emission\ Rate\,\frac{lb}{10^6\ Btu} \times Energy\ Rate\,\frac{Btu}{KWh} \times \frac{10^3\ KWh}{MWh}$$

Where:

$$Energy\ Rate\ (Heat\ Rate) = 6.895 \times 10^6\,\frac{Btu}{MWh}\,(LHV)\,(per\ B\,\&\,V)$$

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5 Ibid., § 1.4.2.2, Table 1-8.

Table K-1 Estimated Greenhouse Gases Emissions

Gas	Emissions (tons/year)	Emissions (lbs/MWh @ the Busbar)	Emissions (Metric Tons/year)	Emissions (KG/MWh at the Busbar)
CO_2	2,375,720	892	2,155,253	410
CH_4	42.7	0.00	38.7	6.53 E-9
N_20	4.3	0.00	3.9	0.65 E-9
CO	1226.0	0.46	1,112.42	0.21
NO_X	220.9	0.08	200.4	0.04
SO_2	13.7	0.01	12.5	0.00
VOC	149	0.064	134.89	0.03

Additional Greenhouse Gas Impacts

The IPCC has developed a GWP factor for most of the direct greenhouse gases. The GWP is a measure of the relative radiative forcing impacts of various greenhouse gases. It is defined as the cumulative radiative forcing (including both direct and indirect effects) over a specified time horizon. The entities that are party to the United Nations Framework Convention of Climate Change (FCCC) have agreed to use GWPs based on a 100-year time horizon. The forcing is measured relative to a reference gas, CO_2, and is expressed in terms of metric tons of carbon equivalent. GWP factors have not been established for the indirect greenhouse gases because there is no agreed upon method to estimate the contributions of these gases to radiative forcing.

Table K-2 summarizes the metric tons of carbon equivalent which were determined using calculated emission values, the GWP factors, and the following equation:[6]

$$MCTE = (MT\ of\ \ gas) \times (GWP) \times \frac{12}{44}$$

where:

$$MTCT = metric\ tons\ of\ \ carbon\ equivalent$$

$$GWP = global\ \ war\min g\ \ potential$$

$$\frac{12}{44} = Ratio\ of\ \ mass\ of\ \ carbon\ to\ mass\ of\ \ carbon\ dioxide$$

Table K-2 Estimated Global Warming Impact

Gas	100-YearGlobal Warming Potential[7]	Metric Tons of Carbon Equivalent
CO_2	1	587,796
CH_4	21	221.8
N_2O	310	327.2